Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories

Laboratoires de recherche minière

Canada

Freezing of Backfilled Stopes in Permafrost: Natural Potential in Canadian Mining Areas

G. Knight

MRL 92-057(R) May 1992

This document is an unedited internal report prepared primarily [illegible] and distribution. It does not represent final expression of the opinions of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport [illegible] rédigé principalement pour fin de diffusion et de documentation interne. Il ne représente nullement l'expression définitive de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

12 pp

MICROMEDIA

Freezing of Backfilled Stopes in Permafrost: Natural Potential in Canadian Mining Areas

G. Knight

Abstract

The objective is to determine the maximum rate of ice formation underground in backfill using natural cooling. It is shown that it is possible to freeze backfilled stopes in winter using the low temperatures of the outside air in northern Canada. Ice can be used instead of cement to strengthen backfill to improve support in mining.

KEYWORDS: Backfill; Ice as cement in backfill; Rate of freezing; Thin layers, Natural cooling.

* Research Scientist, Sudbury Laboratory, Mining Research Laboratories, CANMET, Energy Mines and Resources Canada, Ottawa, Ontario.

Introduction

Backfill placed in stopes after extraction of ore in mines is used to support the adjacent rock. If strong support is required, as when mining the adjacent pillar, the backfill is strengthened with cement so that the free face will be self supporting while exposed in the next stage of mining. In cold mines it is possible to use ice as the cement. This report applies the computer models for heat transfer developed previously(Knight 1989, 1991a) to determine the potential for freezing backfill in Canada. This is an extension to other studies using these heat flow models(Knight 1991b,c,d, 1992a,b).

Frozen backfill is used in one mine in canadian permafrost. The ore body is mined in 15 metre wide stopes across the width leaving 18 metre wide pillars. The stopes are mined in one or more thirty metre lifts backfilling each lift to act as a floor for the next lift and as a support for mining the adjacent pillar. During pillar mining the frozen backfill stands unsupported to the full height of 90 metres.

Heat transfer to the air can be expected to be greatest if the surface is maintained at the highest temperature possible and the air temperature at the lowest(Lozowski 1991, Knight 1992b). This can be done if the freezing occurs at the surface rather than in the body of the backfill. The surface can be maintained at or near the freezing temperature if the backfill is fed continuously or in thin layers. The layers should be thin, so that the resistance to heat flow through the ice layer is only a small proportion of that through the stagnant air boundary layer.

Lozowski et al(1990) have suggested that the ice-air heat transfer coefficient is variable in the 10 to 30 W/(m.^{0}C) range. There have been suggestions that it increases with the temperature difference to the 1.25th power(Schofield 1950).

Another mechanism for heat transfer, radiation, also exists. Assuming black body radiation and that the rock surfaces are cooled to the air temperature then the 'maximum' thickness of ice that can

be formed in one day is calculated. Experimental determinations of the ice-air heat transfer coefficient often include the radiation component.

It is presumed that the backfill needs to be fluid to be applied in thin layers, although a granular material could be spread and compacted mechanically. The backfill suspension can be any solid particulate matter in any fluid. Tailings or sand in water are the materials normally available for hydraulic placement. The approximate thermal properties of backfill that could be placed hydraulically are given in table 1.

Table 1 Thermal Properties of Frozen Fills

Material Water/ Tailings ratio	Thermal Conductivity W/m.^{0}C	Specific Heat kJ/m^3	Latent Heat kJ/m^3
100/0	2	2000	288000
50/50	2	2040	144000
25/75	2	2060	83750

The Computer Simulation Model

The computer simulation models were described by Knight(1989, 1992a). The temperature data preparation, HTDBXDB, program has been modified (Knight 1992c) to calculate the maximum amount of ice that can be formed in each month from above ground hourly reading dry bulb temperatures. The results are given for selected weather stations across northern canada. It is assumed that:

- The surface air temperature is applied to the water surface and that as ice is formed water is continuously added at the same rate.
- The airflow is large so that the warming of the air is

negligible.

- The surfaces are 'blackbodies' and radiative heat transfer is a maximum. The rock surfaces are assumed to be cooled to the air temperature.
- Because the heat transfer coefficient is not known 3 estimates are used to cover the possible range.

A second method is also available to estimate the potential from published climate data. The ice formation is proportional to the total degree days of frost except for the model which assumes that the heat transfer coefficient is a function of the power of the temperature difference. This can be calculated using the equation

$$ID = HTC \cdot DD \cdot TIME / LTF$$

Where ID is the depth of ice formed in one year
HTC is the heat transfer coefficient
DD is the degree days below the freezing point.
TIME is the number of seconds in a day = 86400
and LTF is the latent heat of fusion of ice per cubic metre
$=2.88 \cdot 10^{8}$ J per cubic metre

Thus $ID = HTC \cdot DD \cdot 3 \cdot 10^{-4}$ metres per year

Total annual degree days of frost below 0 ^{0}C are given in the climate atlas (ACS 19). The heat transfer coefficient has not been determined for the conditions of interest.

Results

The weather stations examined are shown in table 2.

Table 3 shows the maximum freezing potential in metres of ice found at the weather stations selected. This was carried out for two values of the ice-air heat transfer coefficient(HTC), 20 and 30 and for the blackbody radiation heat transfer. Normally one would expect the radiation transfer to be included in the ice-air coefficient in an experimental determination.

Table 2 Weather Stations Examined with Comments on Data
Records are dry bulb temperatures read hourly (Env. Can. Code # 078)

P*	#	Place	Code #	Year	Days	Comments
BC	1	Dease Lake (Cassiar)	1192340	1990	365	between 17 and 8 hrs read every 3 hrs
Y	1	Dawson A	2100420	1990	365	readings missing between 22 and 6 hours
	2	Ross River A	2100940	1990	364	readings mssng between 16 and 9 hrs & 31/1
	3	Watson Lake A	2101200	1990	365	4 missing hourly readings
	4	Whitehorse A	2101300	1990	365	
NWT	1	Hay River A	2202400	1990	365	
	2	Yellowknife A	2204100	1990	365	
	3	Iqaluit A	2402590	1990	365	
	4	Nanasivik A	2402730	1990	306	readings missing hours 17-8, Sundys, hldys
	5	Resolute A	2403500	1989	365	4 missed hourly readings
A	1	Fort McMurray A	3062693	1990	365	
Ssk	1	La Ronge A	4064150	1990	365	
Man	1	Flin Flon A	5050960	1990	365	readings missing between 22 and 6 hours
	2	Thompson A	5062922	1990	365	
Ont	1	Sioux Lookout A	6037775	1990	334	July readings missing
	2	Geraldton A	6042716	1990	365	
	3	Sudbury A	6068150	1990	365	
	4	Kapukasing A	6073975	1990	365	1 missed hourly reading
	5	Moosonee	6075425	1990	365	readings only every 6 hours
	6	Timmins A	6078285	1990	365	
PQ	1	Val Dor A	7098600	1990	365	
	2	Inukjuak A	7103282	1990	365	
	3	Schefferville A	7117825	1990	365	
Lab	1	Goose A	8501900	1990	365	
	2	Wabush Lake A	8504175	1990	365	

* Province or Territory abbreviation and number used in table 3

Table 3 Maximum Potential Ice Formation at Selected Sites

P	#	In Each Month for HTC= 20									HTC			Radiatn
		1	2	3	4	5	9	10	11	12	20	30	power	
		Maximum depth of ice formed in metres												
BC	1	3.1	2.7	0.9	0.2	0.01	0.02	0.4	2.6	3.1	12.98	19.48	14.32	2.726
Y	1	5.4	5.9	1.7	0.2	0.01	0.02	0.9	4.9	5.1	24.05	36.08	45.01	4.761
	2	4.6	4.1	0.6	0.05	0	0	0.5	4.2	4.9	18.87	28.31	30.57	3.803
	3	4.2	3.9	1.2	0.01	0	0.02	0.6	3.9	4.5	18.59	27.88	26.99	3.794
	4	3.2	3.6	0.8	0.16	0.01	0.02	0.4	3.5	3.1	14.91	22.37	19.25	3.084
NWT	1	4.6	4.6	1.6	0.59	0.06	0	0.6	3.5	4.7	20.10	30.15	28.25	4.115
	2	5.1	5.2	2.3	0.94	0.11	0	0.8	3.7	5.3	23.42	35.13	35.94	4.748
	3	5.4	5.8	4.0	2.9	0.84	0.03	1.2	2.2	5.1	27.40	41.10	40.63	5.574
	4	5.3	6.1	4.5	3.6	1.9	1.04	3.2	4.2	5.6	35.58	53.38	52.1	7.246
	5	6.5	5.8	5.7	3.5	2.4	0.86	2.9	4.8	5.7	38.4	57.5	64.33	7.682
Alt	1	3.2	3.4	0.8	0.3	0.01	0	0.3	2.4	3.9	14.41	21.62	17.71	2.995
Ssk	1	3.3	3.6	1.1	0.5	0.03	0	0.24	2.0	4.0	14.72	22.08	18.03	3.062
Man	1	3.4	3.6	1.1	0.4	0.01	0	0.17	1.7	4.1	14.52	21.78	17.19	3.029
	2	4.3	4.1	1.7	0.9	0.12	0.04	0.55	2.1	4.8	18.76	28.15	24.92	3.869
Ont	1	2.4	2.6	1.2	0.44	0.02	0	0.04	0.8	3.1	10.53	15.79	10.08	2.236
	2	2.5	2.5	1.4	0.5	0.05	0.01	0.14	0.8	3.0	10.90	16.35	10.52	2.315
	3	1.3	1.8	0.9	0.23	0	0	0.05	0.4	1.5	6.20	9.30	3.98	1.353
	4	2.4	2.5	1.3	0.56	0.05	0.01	0.11	0.6	2.6	10.14	15.21	9.30	2.161
	5	3.2	3.4	1.6	0.84	0.11	0.02	0.07	0.7	3.0	12.93	19.39	10.08	2.721
	6	2.1	2.3	1.2	0.43	0.02	0.01	0.11	0.6	2.3	9.04	13.57	7.93	1.935
PQ	1	1.9	2.5	1.3	0.4	0.01	0	0.10	0.7	2.1	9.00	13.48	7.71	1.926
	2	4.7	5.4	3.3	2.2	0.71	0.02	0.34	1.1	3.7	21.62	32.44	28.09	4.464
	3	4.5	5.0	2.7	1.6	0.37	0.02	0.55	1.8	3.8	20.30	30.45	25.76	4.202
Lab	1	3.5	3.9	1.9	0.61	0.09	0	0.19	0.71	2.8	13.74	20.62	13.95	2.903
	2	4.0	4.4	2.3	1.0	0.17	0	0.40	1.5	3.5	17.37	26.05	20.35	3.624

The alternative approach from degree days is calculated as:

For HTC=20 Ice depth = 6 . Degree Days / 1000
for HTC=30 Ice depth = 9 . Degree Days / 1000
for Radiation Ice depth = 1.3 . Degree Days / 1000

The isotherms for degree days below the freezing point are reproduced from (Atmospheric Env.) in figure 1. For 2 of the stations examined Sudbury and Resolute the degree days below freezing are about 1000 and 6250 respectively. At an HTC of 20 this would give potential ice formation as 6 and 37.5 metres respectively. These values can be compared with the values in table 3 of 6.2 and 38 respectively. This is a very good agreement.

Discussion

The results show that a substantial thickness of frozen fill can be prepared in canadian winters, except in the maritime provinces and coastal BC. The fill should be built up in thin layers as rapidly as it can freeze.

The problems of applying this thin layer technique in practise in stopes are:

- Allowing for the heat loss from the frozen fill to the surrounding rock. Clearly this is only a consideration if the virgin rock temperature is above the freezing point. The heat flow programs would enable calculation of fill heating and cooling under subsequent exposure to cool air and warm rock.
- Determining the appropriate value of the ice-air heat transfer coefficient.
- Maximizing the ice depth by using as high a particle/water ratio mix as possible.
- Determining the strength requirement of the backfill.
- Determining if ice needs to be strengthened by adding interlocking 'stone' particles.
- Transporting the suspension to the stope, pipeline presumably.
- Spreading the suspension sufficiently uniformly over the bottom of the stope. Inequalities will lead to longer total

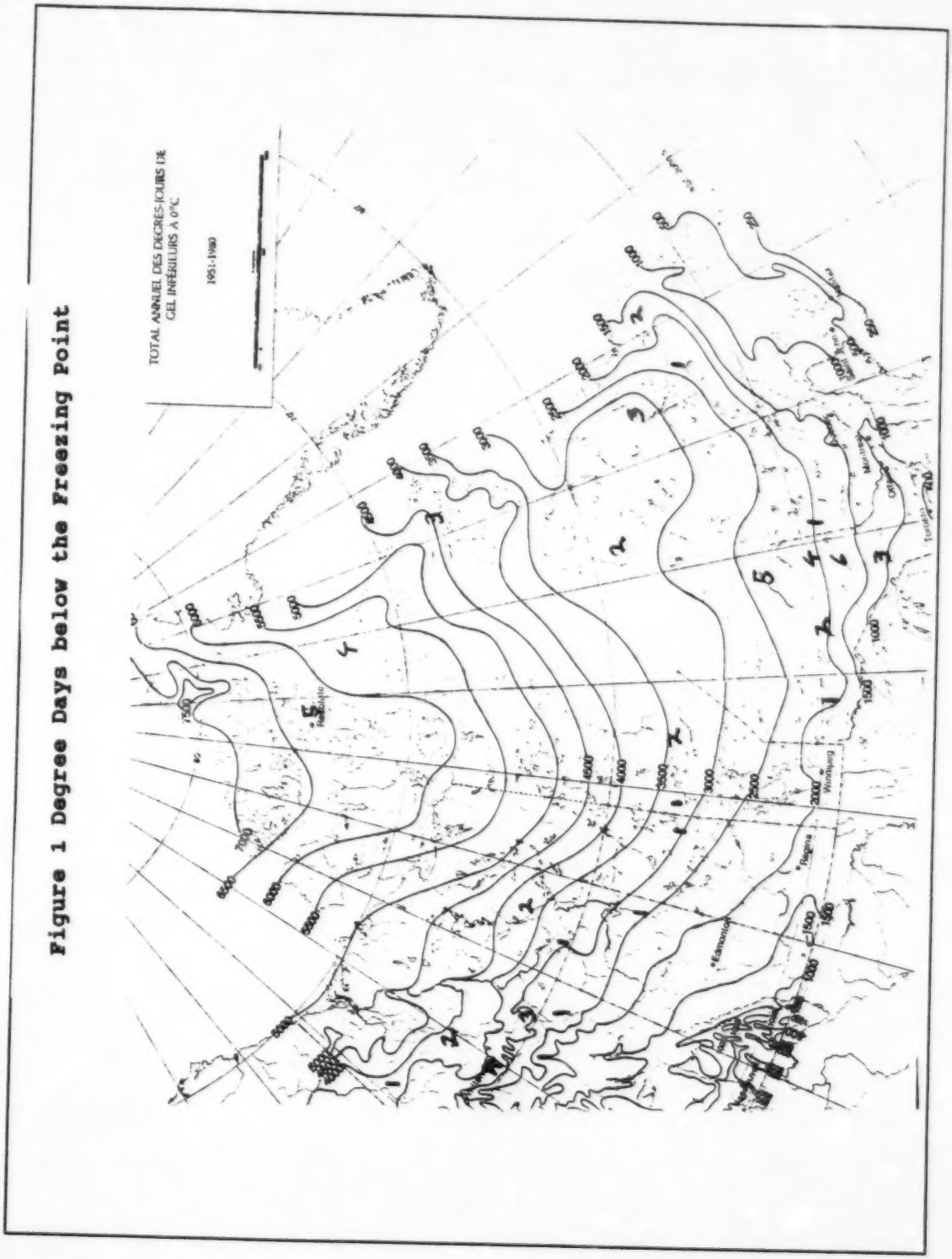

Figure 1 Degree Days below the Freezing Point

freezing times when the scant areas catch up. Continuous feeding at the optimum, just freezing, rate will give the greatest rate of build up of frozen fill. Placing in thin layers about 10mm thick intermittently might give optimum control without sacrificing much speed.

- Controlling the rate of placement in accordance with the rate of freezing determined by the variable air temperature in the stope.
- Determining the optimum tailings treatment, rejection of slimes, etc. for placement in the stope and minimisation of environmental effects.

Monitoring of the thin layer placement and freezing could possibly be carried out with a twisted twin, a naked or leaky coax cable and a time domain reflection (TDR) monitor(Topp 1980, Tan 1992). It is suspected that this would be sensitive enough to detect and measure the change in inductance as water freezes. Essentially this is expected to detect freezing fronts and possibly also impedance differences between ice and water in a practical mining situation.

Acknowledgements

The author wishes to thank the employees of Polaris Mine, Cominco Ltd excellent visits and discussions on the mine problems in order to develop the approaches given in this paper. The author also wishes to thank his colleagues in MRL for assistance in programming.

References

Atmospheric Environment Service Climate atlas *Map series 1 Environment Canada, Atmospheric Environment Service, Ottawa Ont* 1981

Lozowski E.P. and S.J. Jones Some thermal and mechanical properties of flooded ice. *IMD/NRC rep LM-1990-01. National Research Council, St. Johns Newfoundland.* 1990

Lozowski E.P., S.J. Jones and B. Hill Laboratory measurements of growth in thin ice and flooded ice. *Cold Reg. Sci. Technol. 20 pp 25-37* 1991

Knight G. Bibliography on heat flow and problems in cold mines. *Energy Mines and Resources Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 88-125(R):* 1988

Knight G., R.F. Boyle and M. Boutin Computer simulation of heat flow in freezing fill in cold mines. *Energy Mines and Resources Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 89-81(R):* 1989

Knight G. Freezing of backfilled stopes in permafrost: Manual computer simulation models. *Energy Mines and Resources Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 91-114(R):* 1991

Knight G. Freezing of backfilled pillars in permafrost: Effect of adjacent airways and filling rates. *Energy Mines and Resources Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 91-097(R):* 1991

Knight G. Freezing of backfilled stopes in permafrost: Effect of adjacent airways. *Energy Mines and Resources Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 91-099(R):* 1991

Knight G. Freezing of backfilled stopes in permafrost: Effect of air temperature variation pattern. *Energy Mines and Resources*

Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 91-113(R): 1991

Knight G. Freezing of backfilled stopes in permafrost: In mine experiments stopes 207 and 217. *Energy Mines and Resources Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 92-002(R):* 1992

Knight G. Freezing of backfilled stopes in permafrost: Maximum rate: Thin films and continuous feed *Energy Mines and Resources Canada, Mining Research Laboratories, OTTAWA. Divisional Report MRL 92-043(R):* 1992

Schofield F.H. Heat, convection of. *in Dictionary of Applied Physics, R. GLazebrook(ed), Peter Smith, New York,* Vol I. pp 470-477: 1950

Tan R. Private communication. *INCO Research, Copper Cliff, Ontario.* 1992

Topp G.C., J.C. Davis and A.P. Annan Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. *Water Resources Research 16 (no 3)* pp574-582 1980